DETECTION OF HOLLOW PEARS BY TREE BASED MODELLING ON NON-DESTRUCTIVE ACOUSTIC RESPONSE SPECTRA

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Abstract

After CA storage some pears show internal breakdown and brown discoloration. This internal breakdown can be caused by (a combination of) picking time and storage conditions. On the outside of the fruit no visual evidence is found that there is an internal defect. In times that the quality of horticultural products is a major topic, it becomes a problem in marketing strategies when the consumer finds hollow pears.

Acoustic response spectra already proved to be valuable tool in the determination of some internal characteristics of fruits like the stiffness of tomatoes. The acoustic response spectra show some abnormalities for pears with internal cavities. Classical numerical values (second moment, damping, frequency, ...) based on these spectra, were used to identify non-marketable fruits. An additional fourier series algorithm of the spectrum and the use of "tree based modelling" on the coefficients yielded satisfying results. This made it possible to identify the hollow pears quite adequately.

Since the elaborated procedure is based on a non-destructive measurement, it is possible to incorporate it in a sorting line. In this way a substantial amount of affected pears can be removed, resulting in a better overall quality.

1. Introduction

Although the exact physical and physiological processes are still unclear, both an incorrectly selected picking time and non-optimal atmospheric control during storage (too high CO_2 pressure) can result in the formation of internal cavities in pears (Herregods, 1992). This internal breakdown is an intrinsic quality characteristic of pears. To keep high quality standards, pears with internal breakdown need to be eliminated from the market. However, the internal cavity and its brown discoloration is invisible from the outside.

It is estimated that yearly 1 to 2 % (7 - 20 ton) of the Belgian pears are lost in this way, corresponding with a financial loss of 14 to 20 million Belgian francs. In some years 20 to 30 % of the investigated samples show affected pears resulting for some growers in much higher losses.

No non-destructive measuring techniques exists to discriminate between healthy pears and pears with internal breakdown, although in some cases density sorting has been tried. The non-destructive acoustic impulse response technique, developed by Yamamoto *et al*. (1980), modified by De Baerdemaeker (1988) and Chen (1993) and extended to the application of tomatoes, peaches and pineapples (Chen *et al*., 1990) proved to be a valuable tool in the determination of internal characteristics of the fruit (Armstrong *et al*., 1990 and 1992 and Verreydt *et al*., 1994).

In this report the use of the acoustic impulse response technique is evaluated as a non-destructive measuring technique to distinguish between healthy and affected or hollow pears. The acoustic response spectra of pears with internal cavities show some abnormalities. A correct description of these abnormalities can be used as a criterionf for evaluation. Features extracted from the acoustic response spectra and parameters of a fourier series fitted to the spectra are used in tree based modelling to distinguish between healthy pears and pears with internal breakdown.

2. Materials and methods

A sample of 70 pears (Conference) taken in April 1994 from a local grower with storage problems was measured with the acoustic response technique. The measurement set-up for this technique is represented in figure 1. The pear is placed in a position with its peduncle horizontally. Under the fruit a MC101 microphone is mounted a few centimetres away from and directed towards the fruit. A small impact is given to the equator of the pear. The location of the microphone and of the impact area was determined after studying the different vibrational mode shapes that correspond to the material frequencies of a vibrating pear. It should be noted that because of the pear geometry these mode shapes are very different from those observed previously in nearly spherical fruits like apples, tomatoes, melon, ... (Chen *et al*., 1992, Vandewalle *et al*., 1994,)

The mechanical impact results in a vibration (deformations) of the pear. The general principle used in this measurement is the determination of the resonant frequencies of the pears. At these resonant frequencies the deformations of the pears are maximum. The pressure wave caused by the vibrating pear, is picked up by the microphone and is amplified, filtered and digitised.

A fast fourier transform algorithm converts the time signal into a frequency spectrum. For each pear the frequency spectrum from 300 up to 1300 Hz is measured.

After the non destructive measurement with the acoustic response technique, internal breakdown (hollowness) of the sample of 70 pears was determined in a destructive way by visual inspection.

36 out of 70 pears had internal breakdown. The typical spectra for hollow and healthy pears are represented in figure 2a and 2b respectively. For the spectra of healthy pears there is usually one high peak (Figure 2b), while the spectra of pears with internal breakdown show usually one high peak as well as several smaller ones (Figure 2a).

The relationship between the spectra and the presence of an internal cavity was analysed in two ways: by feature extraction from the spectra and by approximating the spectra with a fourier series.

1. Feature extraction from the spectra

The following features are extracted from the obtained pear spectra:

- the frequency of the highest peak (FreqHP)
- the number of peaks higher than 33 % of the amplitude of the highest peak (N)
- the damping: a measure for the skewness of the highest peak (Damping).
- the moment: the 0th order moment of the spectral curve with the rotation axis passing the highest peak (Moment)
- the area: the surface under the spectrum (Area)

2. Spectrum approximation by a fourier series

The spectra of the pears were approximated with a fast fourier series consisting of an intercept and 24 parameters (12 cosines and 12 sines) (Figure 3). To prevent that the fast fourier series is influenced by the maximum amplitude of the spectrum, all the spectra were normalised so that the highest peak has amplitude 1. A fourier series can express each function as a sum of cosine and sine-functions with a period $2\pi\lambda$ (Titchmarsh, 1967). The multiple correlation coefficient (R^2) between the observed and predicted spectra for all pears (both healthy and affected) was higher than 99 %, indicating a good approximation of the spectra by the fast fourier series, as shown in figure 3.

Since pears with similar flesh firmness but different weights have different resonant frequencies, also the weight of the 70 pears was individually determined.

The above data were analysed with tree based modelling (Classification and Regression Trees) (Breiman *et al.*, 1984). The CART program is an interesting and powerful alternative to parametric methods in classification and regression. Regression and classification are methods that use data to form prediction rules for one variable based on the values of other variables. The construction of classification and regression prediction rules proceeds by a systematic analysis of the whole data set, containing values of the variable to be predicted (healthy or affected) together with the related values of the variables to be used in the prediction rule (for example the coefficients of a fourier series). The CART algorithm selects the variables with a significant prediction level. The program constructs prediction rules in the form of binary decision trees.
After constructing a large tree with only a few observations left in each class, the tree is pruned by 3 fold cross-validation. CART then selects the smallest tree achieving the minimum estimated error rate.
Two trees were generated, one is based on the features extracted from the spectra while the other is based on the fourier parameters of the fitted spectra.

3. Results and discussion

3.1. Decision tree based on features extracted from the pear spectra

Based on the features extracted from the acoustic response spectra a tree with only three terminal nodes was generated (Figure 4), separating healthy and affected pears with an error of 10 %. This means that 10 % of the data is misclassified.

Only two (number of peaks and moment) of the five extracted features are used in the generated tree. All pears with a spectrum with more than one peak higher than 33 % of the amplitude of the highest peak ($N>1$) are classified as pears with internal breakdown (node rule 1). The pears with a spectrum with one peak higher than 33 % of the amplitude of the highest peak ($N\leq1$) are classified as healthy pears if the moment is higher than 1320 (node rule 2) and are classified as affected if the moment is lower than or equal to 1320.

51.4 % of the classified pears had internal breakdown, while 48.6 % was healthy. In the constructed tree pears with internal breakdown have a misclassification probability of 7.1 %, while the chance on misclassification for healthy pears equals 2.9 %.

2. Decision tree based on fourier series

Based on the fourier series parameters a decision tree with five terminal nodes is constructed (Figure 6). The pears are classified as healthy if the fourier parameter “S5” is higher than 0.02 (node rule 1) and the fourier parameter “S2” is higher than 0.101 (node rule 3) or if the fourier parameter “S5” is lower than or equal to 0.02 (node rule 1) and the intercept is higher than 0.183 (node rule 2) and the fourier parameter “S9” is higher than -0.02 (node rule 4). In all the other cases the pears are classified as pears with internal breakdown.

The misclassification error of this tree is only 4.3 %. Affected pears are always correctly classified, while the chance on misclassifying a healthy pear equals 4.3 %. The tree base on the fast fourier series results in a better separation of healthy an affected pears, but has almost no interpretation value for the underlying vibration phenomena.

3. Conclusion

The non-destructive acoustic impulse response technique proved to be valuable tool in the determination of some internal characteristics of fruits. The use of this technique to distinguish between healthy pears and pears with internal breakdown is evaluated.

The acoustic response spectra of pears with internal cavities show some abnormalities. Both feature extraction from the acoustic response spectra and a fourier series approximation of the spectra was used to generate a tree separating healthy and affected pears. The tree based on the feature extraction from the acoustic response spectra had only three terminal nodes but a rather high misclassification error of 10 %. The tree generated with the fourier parameters had five terminal nodes and a misclassification error of only 4.3 %. With this algorithm none of the affected pears was misclassified.

The described procedure to find pears with internal breakdown is based on a non-destructive technique (acoustic impulse response technique). It is possible to incorporate this technique in a sorting line. In this way, a substantial amount of affected pears may be removed, resulting in a better quality appreciation by the consumer.

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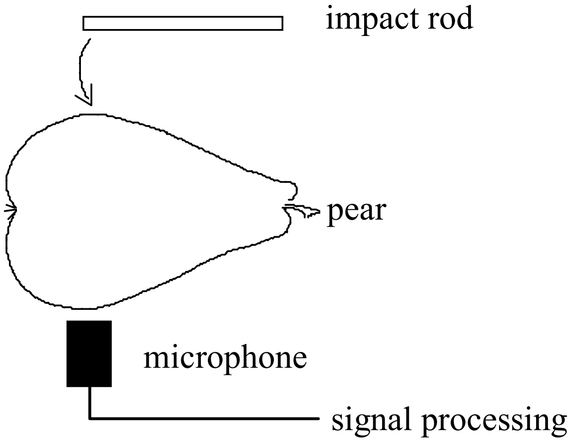

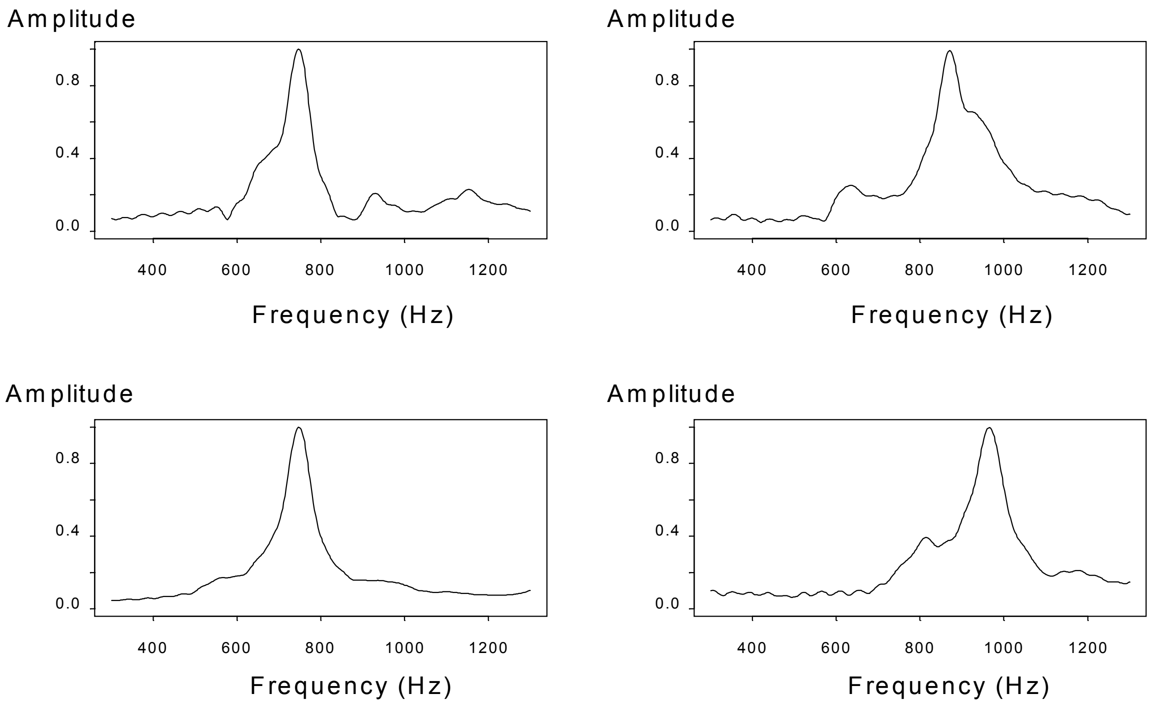

2 a   2 b

Figure 2 - Examples of spectra of affected (2 a) and healthy (2 b) pears

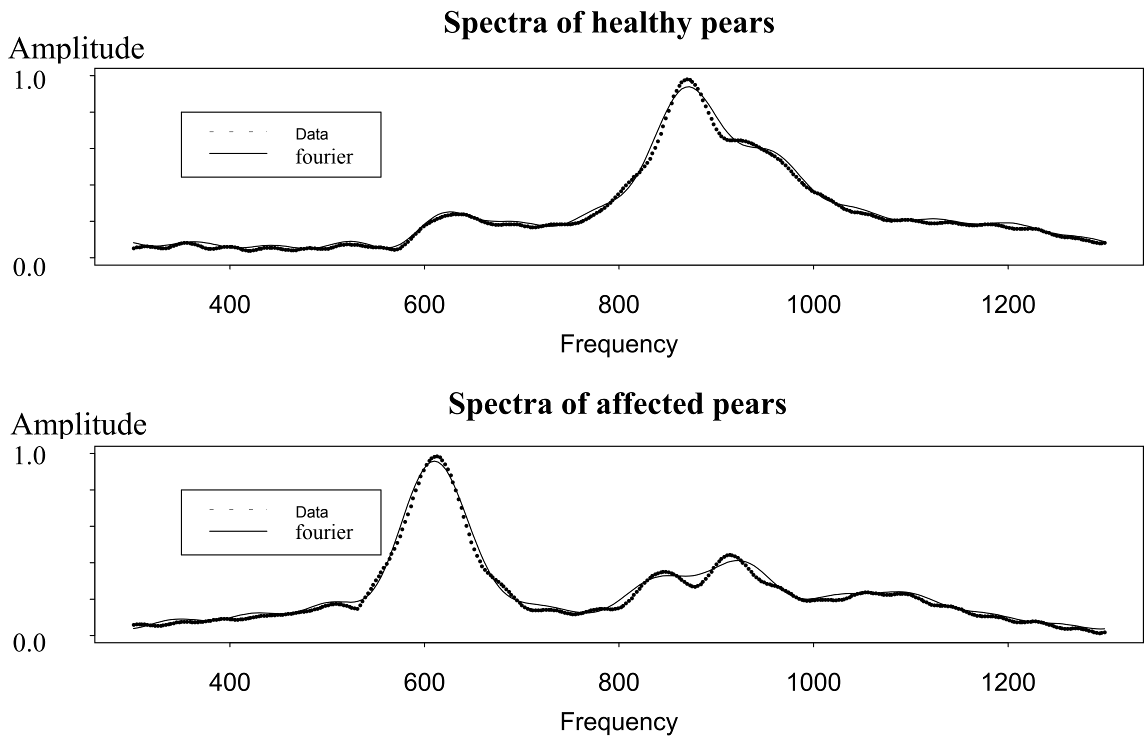

Figure 3 - Spectrum approximation by a fourier series

node rules:

1: N ≤ 1

2: Moment ≤ 1320

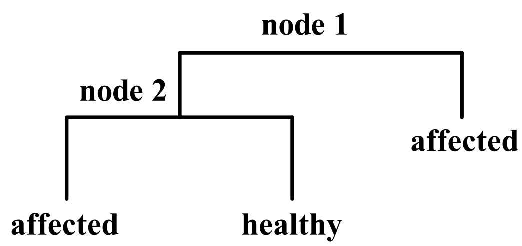

Figure 4 - Tree generated based on features extracted from the spectra

node rules:

1: S5 ≤ 0.02

2: intercept ≤ 0.183

3: S2 ≤ 0.101

4: S9 ≤ -0.02

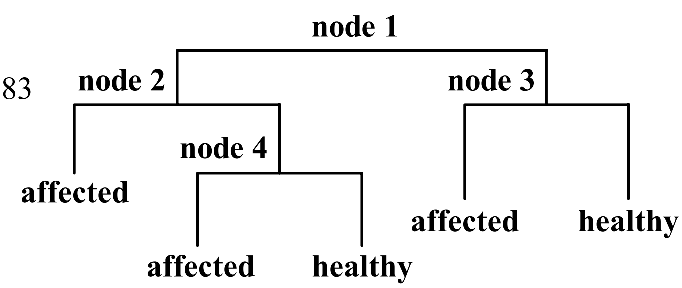

Figure 5 - Tree generated based on the parameters of the fourier series

Tree based modelling

- the whole dataset (70 observations) is used to construct a large tree with only a few observations left in each terminal node
- the large tree is pruned by treefold cross validation
- treefold cross validation is used instead of the standard 10 fold cross validation because with 10 fold cross validation there are only 70/10 = 7 obervations to test the tree, while using 3 fold cross validation there are 70/3 ¸ 23 observations to test the tree.
- treefold cross validation:
  - ♦ the whole dataset is randomly devided in 3 groups (group 1, 2 and 3) containing each 3 observations
  - ♦ group 1 and 2 are used to construct tree 1 and group 3 is used to test the tree
  - ♦ group 1 and 3 are used to construct tree 2 and group 2 is used to test the tree
  - ♦ group 2 and 3 are used to construct tree 3 and group 1 is used to test the tree
  - ♦ the large tree constructed with the whole dataset is pruned until the number of terminal nodes equals the average number of terminal nodes of the 3 trees constructed with 66 % of the whole dataset

Neural network on features

- Type used: backward error propagation
  learning rate = 0.5
- 1 input layer (6 nodes)
- 1 output layer (1 node)
- 1 hidden layer (5 nodes)
- cycli training (52 cases) = 4000
- test sample (18 cases) ==> 6 wrong classified (33 % misclassified)
- all the misclassified cases were affected pears that were classified as healthy